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MRBX - OPERATIONAL EVALUATION

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16. Abstract

This report documents the operational evaluation on MRBX, CG-250000, conducted by the CG R&DC from April 1973 to June 1975. The MRBX is intended for fast personnel rescue missions, achieves speeds in excess of 20 knots, and can survive 10-foot plunging surf. It will perform many missions of the 44-foot MLB, but is particularly suited to shallow inlet and bar areas not served by the 44-foot MLB. The MRBX is a hybrid craft with a deep vee planing forebody and a fully submerged fixed foil aft providing stern lift as well as improved seakeeping characteristics in surf. The craft is powered by a diesel-driven water-jet pump. The Op Eval described herein covers technical evaluation at NAVSEC Norfolk, Coast Guard operation evaluation on the Oregon coast, description of modifications performed and post construction seakeeping model testing. The Op Eval concluded that the MRBX is an effective craft for limited high speed rescue in areas having moderate surf and rough seas.

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1.0 INTRODUCTION

The design objectives for the MRBX specified a boat of the following characteristics:

a. Mission. To provide limited high speed rescue capability in areas having moderate surf and rough seas.

b. Tasks. To provide primary rescue capability at stations having moderate surf and rough sea conditions.

To provide backup capability to the 44-foot motor lifeboat and Coast Guard helicopters for short range missions and those not requiring the extreme weather capability of the 44-foot MLB.

To provide high speed inshore rescue capability in protected shallow water.

c. Design and Hull Characteristics

--Approximate dimensions and displacement:

Length overall	26'0"
Beam	8'0"
Displacement	5200 pounds

--Subdivision - A minimum of three watertight compartments. The design will be such that loss of any one compartment will not lose the boat.

--Self-righting characteristics - To be obtained by a combination of the hull and topside design of the watertight configuration, and selected weight distribution.

--Self-bailing characteristics - To be obtained by the freeboard of the cockpit deck and freeing ports. To reduce the amount of water entrained in the event of capsizing, the cockpit area will be held to a minimum commensurate with other requirements.

--Maneuverability - To be the maximum attainable at both high and low speed for surf operation. Accelerations to be rapid and reliable. The desired tactical diameter in a turn is two boat lengths at 40% power and four boat lengths at full power; the acceptable tactical diameter is three and six boat lengths respectively. The boat should not heel outboard in a tight turn nor show a violent change in the amount of heel during the turn.

--The boat should be capable of sustaining 20 knots in a fully arisen state 3 sea. The boat must provide a tolerable ride under these conditions so as not to reduce crew effectiveness. The boat should have good directional stability, without tendency to broach in a following sea.

--The boat should be capable of traversing a 10-foot plunging surf.

--The rudder, propeller or propulsion device and foils to be such that beaching on sand or gravel is possible. The design shall provide the maximum protection of the propulsion and control elements for shallow water operation.

--Normal crew to be two men. Control of the boat, communications, and navigation to be carried out by the operator.

d. Propulsion and Engineering Features

--Smooth water sustained speed of 25 knots was desired, minimum acceptable 22 knots. State 3 sea sustained speed of 20 knots desirable, 18 knots minimum acceptable.

--The endurance to be 75 miles at maximum speed and 10 hours at cruising speed.

--The electric plant to be an engine-driven alternator with battery system to carry normal electrical load. Battery capacity shall be sufficient to operate navigational lights for 12 hours.

--All equipment must be capable of withstanding momentary inversion due to capsizing and continued operation.

--Shock mountings and structure should anticipate instantaneous loads of up to 12 G's.

--The propulsion and control system must have a high degree of reliability.

The purpose of this report is to describe the technical and operational evaluation of the MRBX boat built to these design objectives and to describe those changes made to the boat to make it acceptable to the operational forces.

2.0 EVALUATION

2.1 Technical Evaluation - NAVSEC Norfolk

The test program at NAVSEC Norfolk was designed to measure and document MRBX in the following technical areas:

1. Powering
2. Maneuvering
3. Human factors
4. Seakeeping
5. Maintenance and repairability

as described in the NAVSEC Norfolk report(2) the conditions and some of the results are as follows:

a. Powering

The MRBX was tested at three load conditions and measurements were made of shaft torque, shaft revolutions-per-minute (RPM), craft dynamic

trim, engine fuel consumption (GPH), and hydrofoil optimum static angle of attack. Performance testing was conducted in water 7 to 9 feet deep with a check for deep water effect, in water 25 feet deep. Towing tests were conducted in water 15 to 17 feet deep.

The three tested load conditions are briefly described as follows:

(1) Light load boat as light as practicable, two men in cockpit, minimum stores and tools, one-third fuel, necessary instrumentation.

(2) Full load/light load plus two-thirds fuel, normal stores and tools.

(3) Overload - full load with the equivalent of four additional men (165 pounds each) in the survivors' compartment or a total displacement that places the cockpit deck at the water surface level, whichever is less. The actual load conditions tested are presented in Table 1. MRBX is shown as built in Figure 1.

TABLE 1

TEST LOAD CONDITIONS

CONDITION	DISPLACEMENT POUNDS	LCG (AFT OF STEP) FEET	MEAN DRAFT FEET
1	7140	0.14	1.90
2	7430	0.80	1.98
3	7980	0.25	2.04

Typical powering and performance characteristics of MRBX are presented graphically in Figure 2 as a function of speed. Test conditions for the results in Figure 2 were calm water with a mean depth of 8 feet. It was estimated, based on other data checks, that a speed loss of about 1 knot would be realized in deeper water.

The results from towing and bollard pull tests are presented in Figures 3 and 4. A typical USN 36-foot LCPL (MKII) was utilized as the towed vessel during towing tests. The LCPL was towed with both a wind-milling propeller and with 600 reverse RPM providing additional resistance to the MRBX. Bollard pull results (Figure 4) were limited to approximately 2500 RPM due to air being drawn down the sides of the craft and into the pump at higher engine RPM while not underway.

Acceleration and deceleration test results are presented in Table 2. These tests were conducted in calm water, 20 feet deep. The stopping distance of MRBX with an approach speed of 22.8 knots to dead-in-water was 2 1/2 to 3 boat lengths.

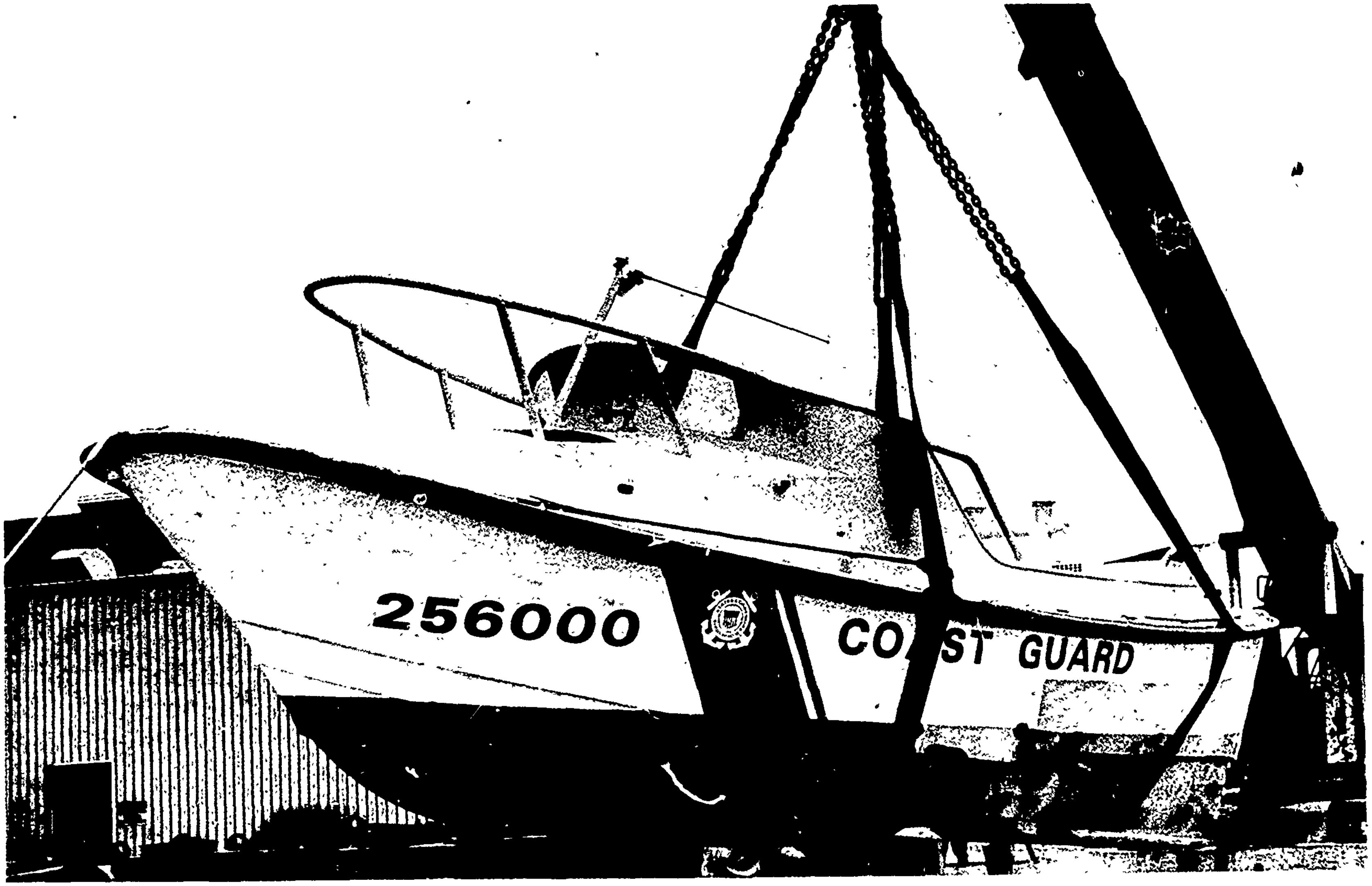


FIGURE 1. MRBX as built in 1972

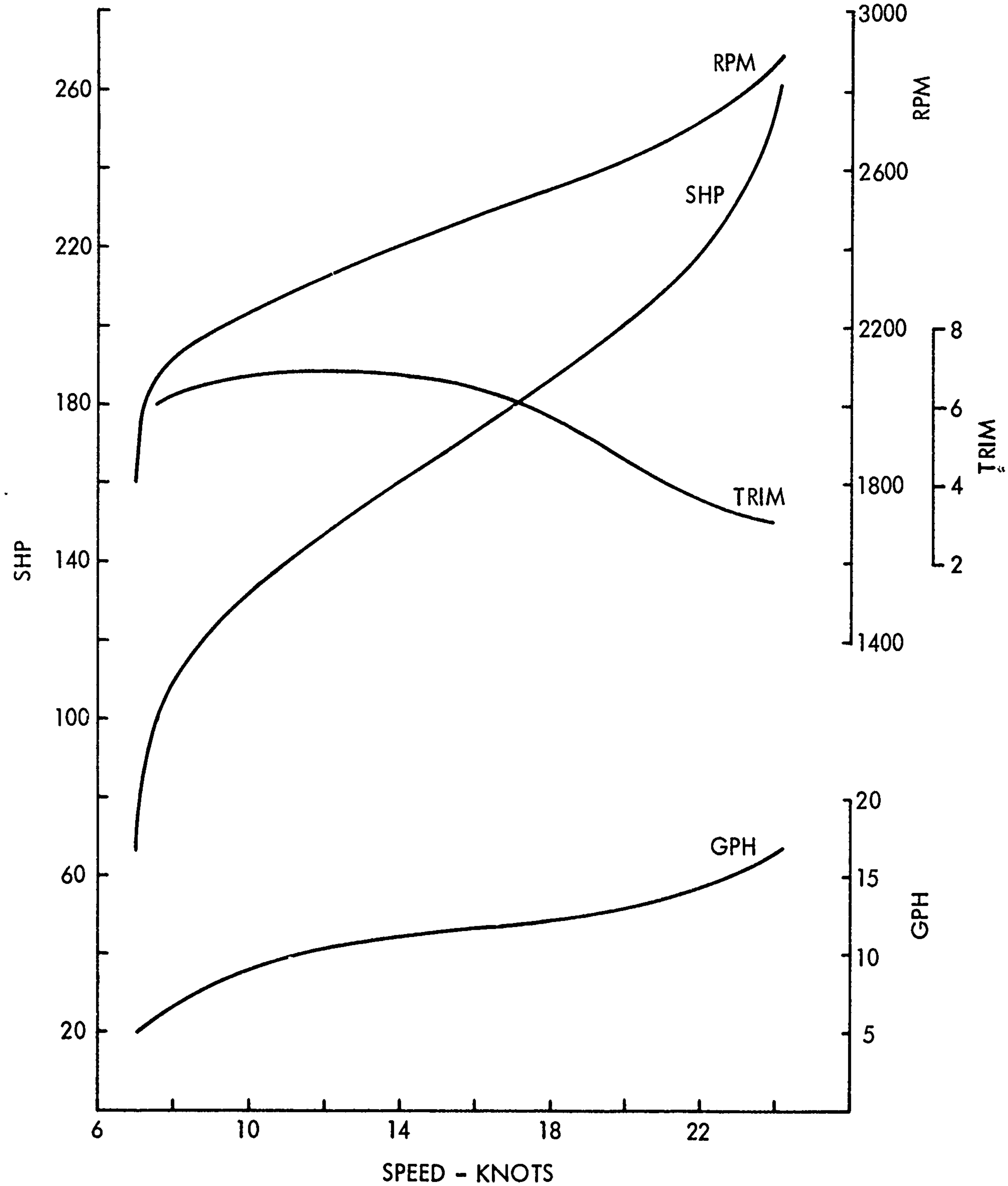


FIGURE 2 - MRBX PERFORMANCE CHARACTERISTICS

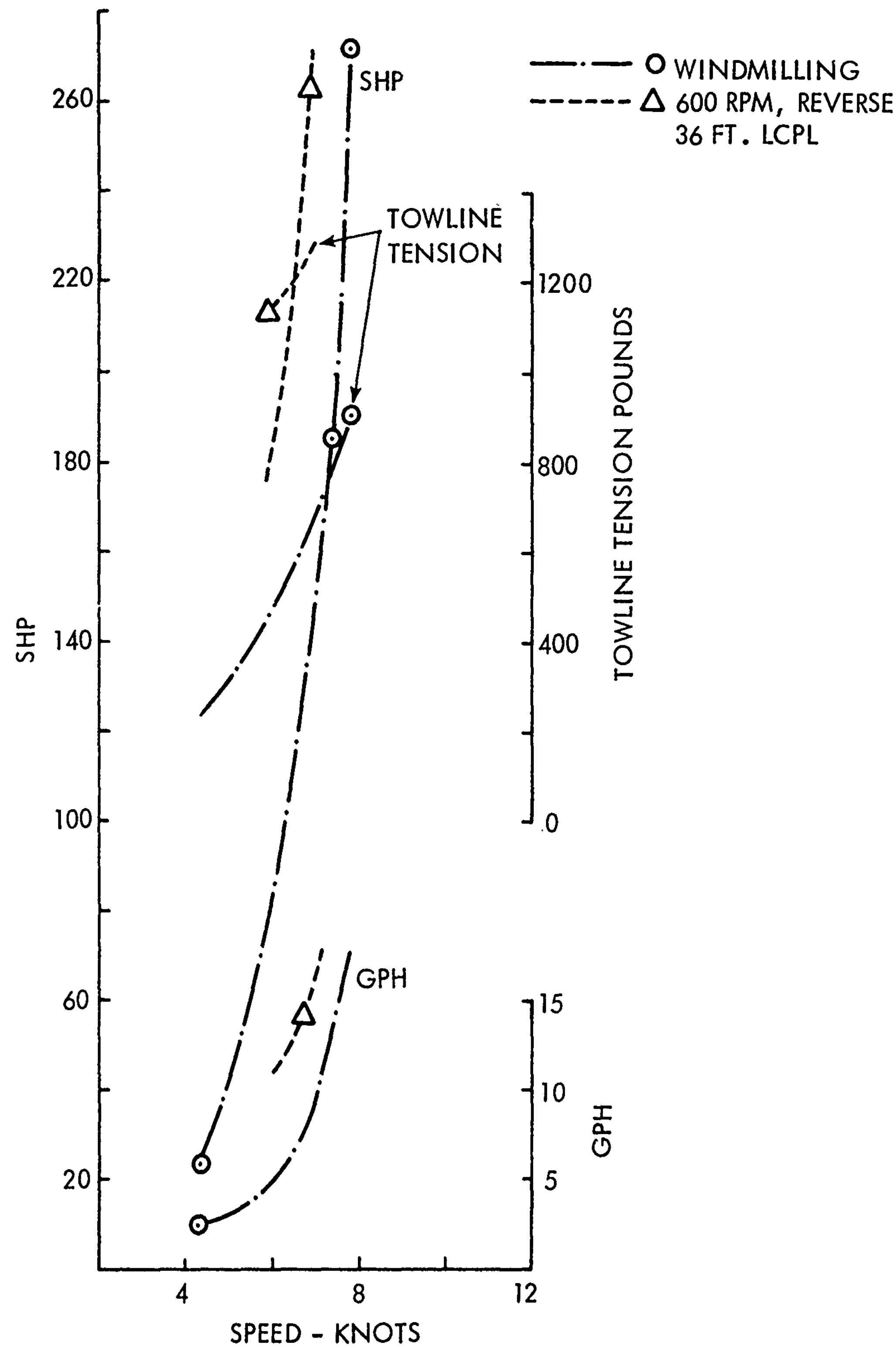


FIGURE 3 - TOWING TEST RESULTS

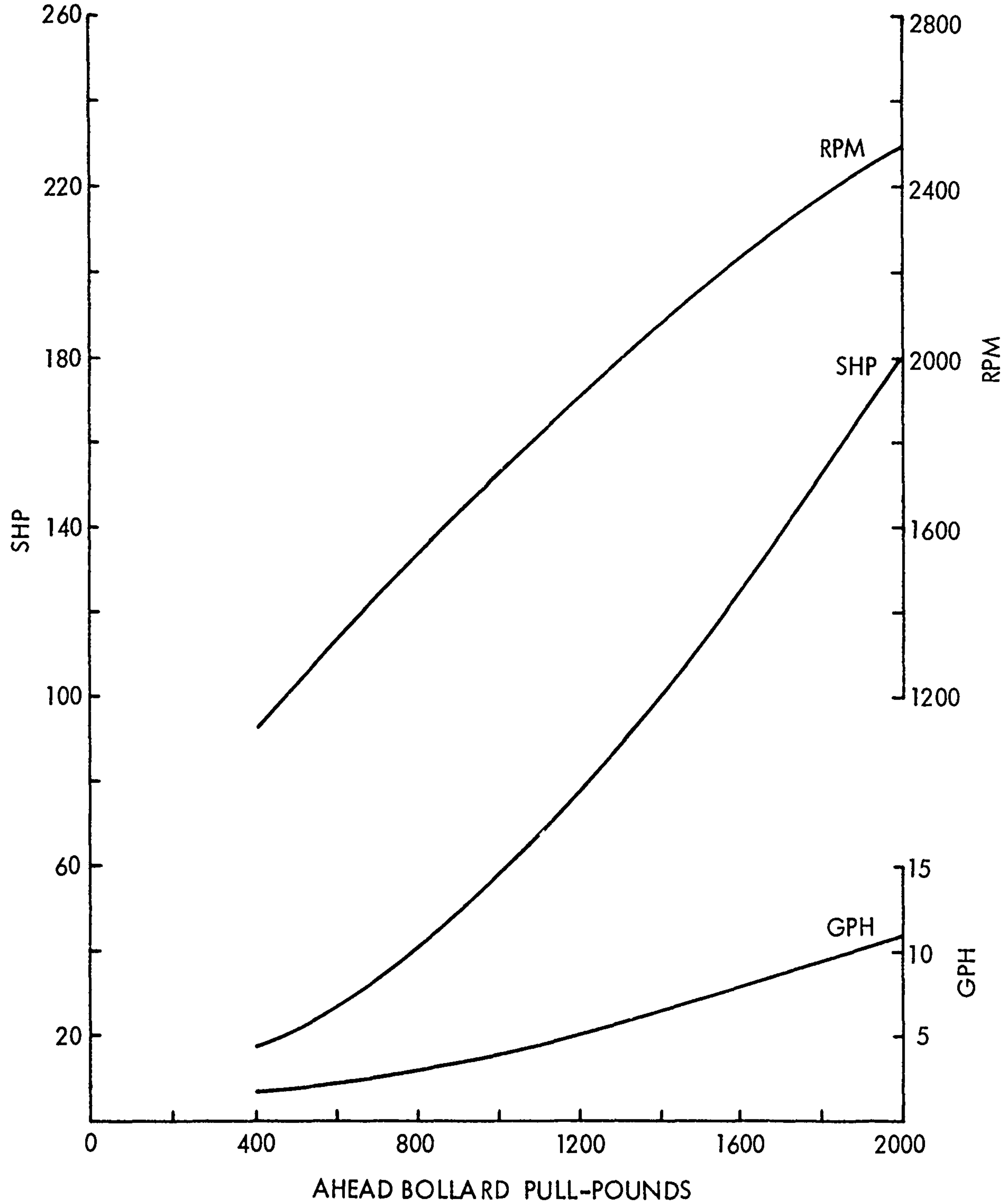


FIGURE 4 - BOLLARD PULL TEST RESULTS

Table 2. Acceleration-deceleration tests.

ACCELERATION: 0 - 22.8 KNOTS	
RUN	TIME - SECONDS
1	19.8
2	20.1
3	18.4
4	20.1
AVG.	19.5
DECELERATION: 22.8 - 0 KNOTS	
RUN	TIME - SECONDS
1	4.2
2	4.3
3	5.0
4	4.7
AVG.	4.6
Δ 2; STATIC TRIM 1.4 DEG BY THE STERN; FOIL ANGLE -0.5 DEG	

b. Maneuvering Characteristics

Maneuvering characteristics for the MRBX were determined in calm water for various load conditions, hydrofoil angles, static trims, and engine speeds. Directional stability and spiral maneuvering tests were conducted in both forward and reverse directions.

The tactical diameter for a full speed maximum helm angle turn was 135 feet or about 5 1/2 boat lengths. The boat heeled into the turn at 15-20 degrees in a full speed, full helm turn.

Forward directional stability tests consisted of steering the craft toward a point on the horizon at various speeds, hydrofoil angles, and load conditions while recording yaw angle (heading) and jet angle (helm position) as functions of time. A very noticeable directional

instability (yaw excursion) occurred at higher craft speeds with high foil angles. The magnitude and frequency of instability decreased as foil angle was decreased in a more negative direction. Decreasing foil angle increases running trim and therefore increases after-body wetting resulting in improved directional stability. However, increasing after-body wetting increases hull drag and decreases craft speed.

Astern directional stability tests were run. The MRBX was found to be directionally stable in reverse only at low engine speeds and in calm water conditions. Once the bow was allowed to yaw in either direction it would continue to do so irrespective of counter helm. Above 1800 RPM pump cavitation would occur due to air being drawn down the sides into the pump.

The forward and astern "controls-fixed" stability of MRBX was evaluated by conducting Dieudonne spiral maneuvers at various engine speeds and displacements. The results demonstrated desirable, "negative stability index" characteristics for ahead operations. Astern spiral results indicated instability and once reverse turning was initiated in one direction by full jet angle, turning continued in that direction irrespective of jet position, and regardless of which direction the maneuver was started.

c. Seakeeping Characteristics

The MRBX was tested in rough water to determine seakeeping characteristics for various sea conditions and headings to the sea. Tests in breaking waves and surf were not conducted.

Seakeeping tests were conducted on three different days in three different types of seaway. The seaway was measured with a wave buoy on two test days and was estimated for the third day which was too severe to safely launch the wave buoy. The sea conditions are listed in Table 3 in order of increasing severity. The 1 March condition was a relatively mild, deep water, long wavelength type of sea or swell condition that placed no limitations on the operation of the MRBX. The 22 February condition consisted of short, steep waves of short wavelength with a fresh wind of approximately 30 knots. The main difficulty presented by this condition was constant wetting of the cockpit with resulting restricted visibility. The third sea condition, 27 February, was by far the most severe. This test was conducted near shore at the entrance of an inlet with gale winds driving the sea into the inlet. The waves were steep, short, and occasionally breaking at the crests. Operations in these head seas was restricted to 2700 RPM. Operation in this following sea was critical because of a tendency to broach near the wavecrests. The broaching tendency was countered by powering over the crest and onto the back of the next wave instead of trying to hold position on a given wave with questionable astern capability.

Table 3. Sea conditions.

1 MAR 1973 — OFF CAPE HENRY	
AVERAGE WAVE HEIGHT	1.3 ft
AVERAGE WAVE PERIOD	2.8 sec
AVERAGE 1/3 HIGHEST (SIGNIFICANT)	2.3 ft
AVERAGE 1/10 HIGHEST	2.9 ft
MAXIMUM WAVE HEIGHT	6.2 ft
22 FEB 1973 — N.W. OF LITTLE CREEK INLET	
AVERAGE WAVE HEIGHT	1.0 ft
AVERAGE WAVE PERIOD	2.2 sec
AVERAGE 1/3 HIGHEST (SIGNIFICANT)	1.8 sec
AVERAGE 1/10 HIGHEST	2.7 ft
MAXIMUM WAVE HEIGHT	4.6 ft
27 FEB 1973 — NEAR ENTRANCE-LITTLE CREEK INLET	
ESTIMATED RANGE OF WAVE HEIGHTS	5-8 ft
ESTIMATED RANGE OF WAVE LENGTH	35-50 ft
SOME BREAKING CRESTS	

The frequency of encounter and peak-to-peak magnitude of craft accelerations are shown in Figure 5. The locations of acceleration measurement were at the helm, 3.2 feet forward of the hull step, and at the bow, 9.1 feet forward of the hull step. The maximum accelerations at each location were also recorded. Accelerations less than 0.25G were not reported. The significantly lower frequency of encounter reported for the severe sea condition, Figure 5, was due to the reduced operating speed, 2700 RPM. Accelerations at other attitudes to the sea were of low magnitude and frequency of encounter when compared to the head sea conditions.

Frequency of encounter and peak-to-peak pitch angles are presented for head seas in Figure 6. The maximum pitch-angle displacement measured for each sea condition was reported. The pitch results were recorded simultaneously with the acceleration results and, in all cases, the results represent a sample of at least 100 encounters.

Motions and accelerations aboard the MRBX during seakeeping tests were acceptable from a crew safety standpoint. Crew fatigue will be a factor during long endurance operations under the more severe conditions but a reduction in operating speeds from those conditions reported should reduce fatigue significantly. No structural damage was noticed either during or following seakeeping tests.

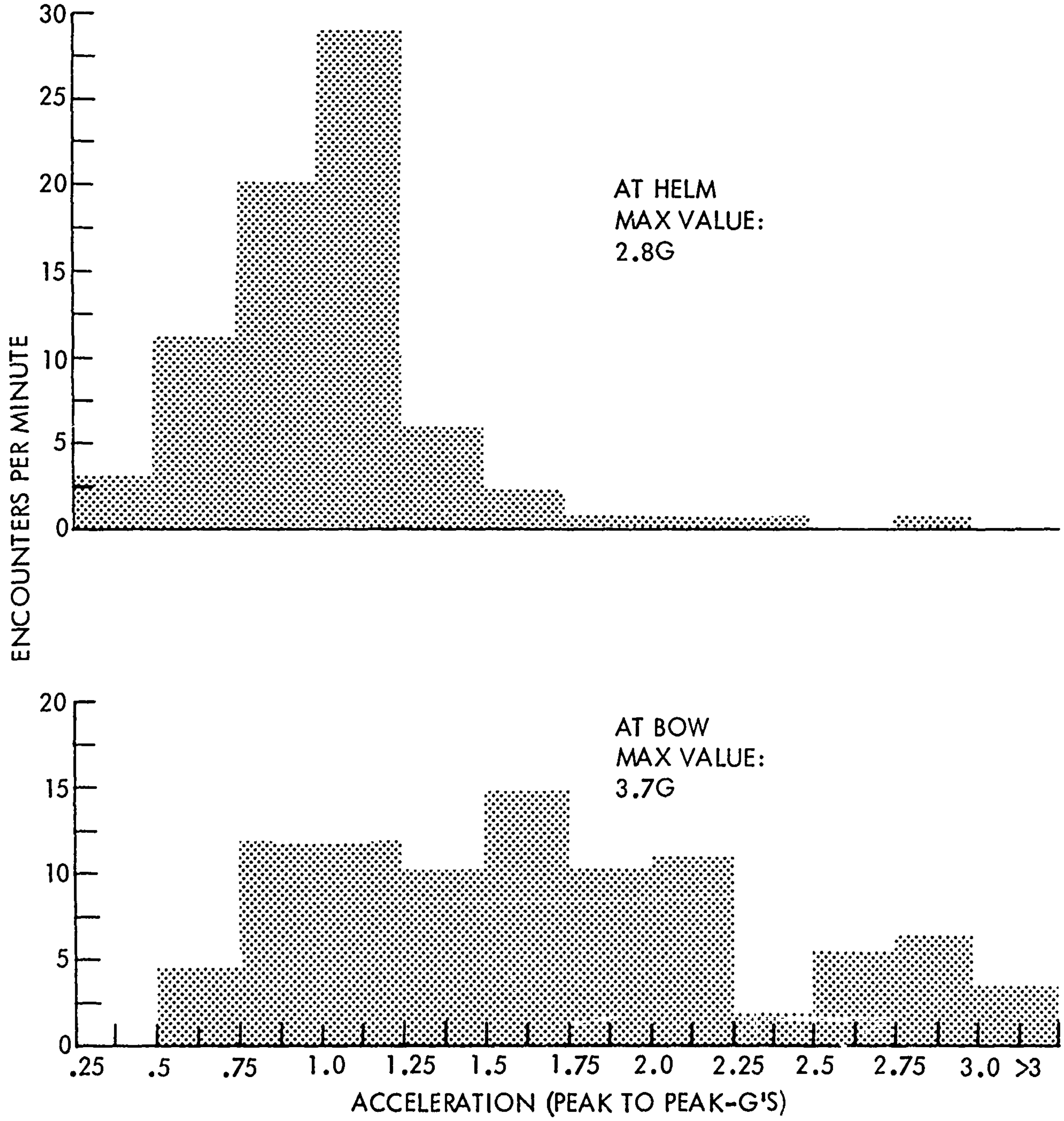


Figure 5. Accelerations in sea states.

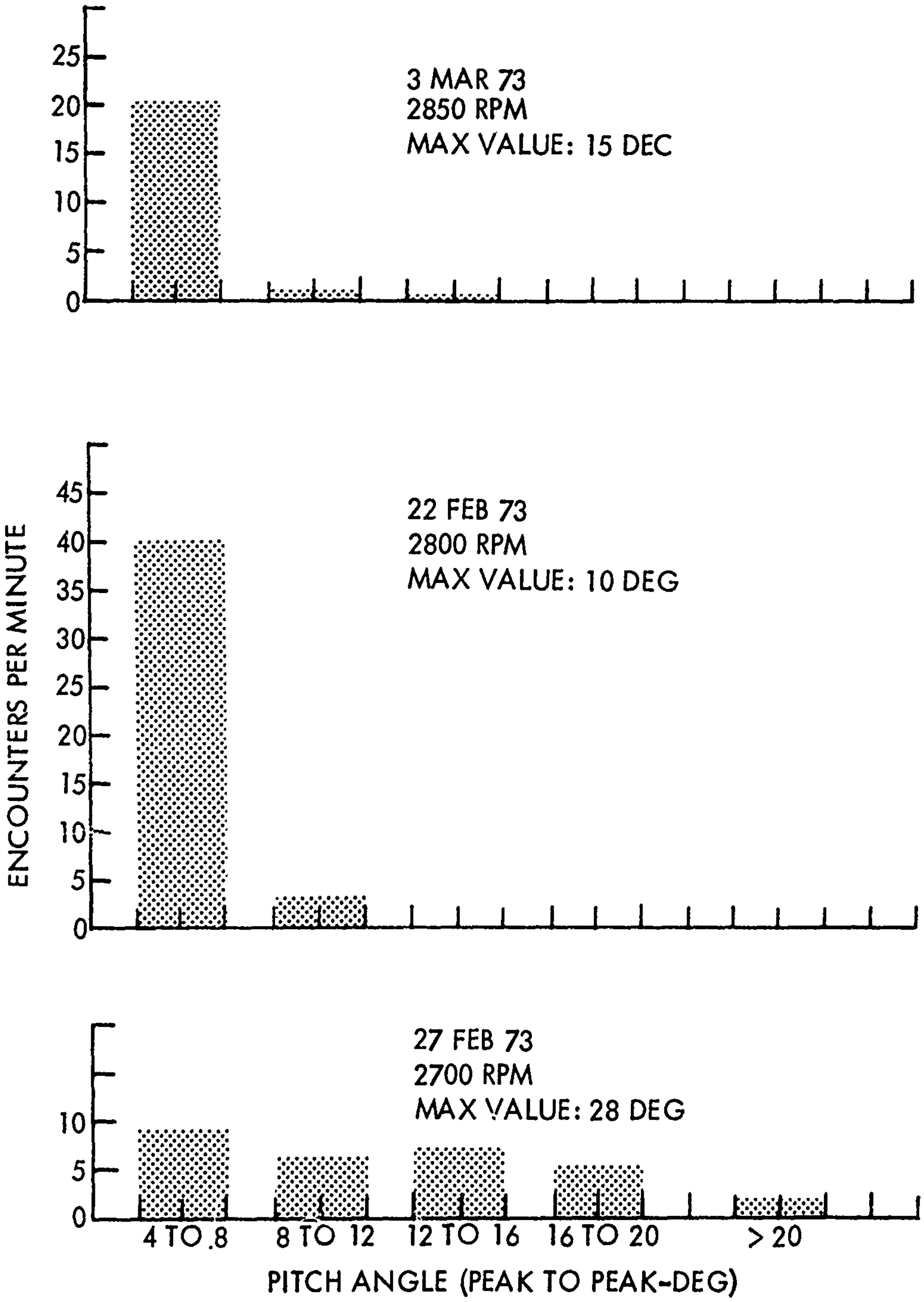


Figure 6. Pitch angles in sea states.

d. Human Factors

An awareness of factors that related to the compatibility of crew to craft was maintained throughout the testing of the MRBX. These factors lent themselves to a qualitative assessment only.

The high spray shield on top of the cabin obstructed the forward vision of the coxswain, who was of average height, and was ineffective in protecting the crew from spray in rough water conditions. The coxswain's seat was of no use when underway and was a hazard in rough water operation. The position, layout, sensitivity and force required to operate the craft controls was satisfactory.

The location of the radio and depth sounder readout near the coxswain's right foot was unacceptable and a higher, more central position was suggested. There were many sharp and unnecessarily dangerous projections. Brackets, protruding bolt-ends, fixtures and latches for doors, boat hooks, and the anchor all needed improvement. Hand-holds were numerous and generally well placed. The forward handrail on the cabin top was high enough and far enough outboard that it might trap a crewman between it and a larger, higher vessel alongside due to the inherent large amplitude static rolling characteristics of the MRBX. During rough water operation with a strong wind over the starboard side, craft performance was severely limited by coxswain visibility. Water that was shed from the bow was blown into the coxswain's face. Noise in the manned areas of MRBX was within acceptable limits.

e. Maintenance and Reliability

The MRBX was delivered for testing with 22 engine operating hours recorded and during the test period, 126 additional engine operating hours were accumulated. Maintenance and repairs required during this period together with pertinent comments were as follows: Engine lube oil and coolant solution levels were checked every operating day before start-up and replenished when necessary; which was infrequently and routine.

Non-routine checks or maintenance of the engine or any other engine compartment equipment such as engine-driven bilge pump, raw water strainer, etc., was extremely difficult due to the engine compartment cover design incorporating some 125 quarter-inch bolts with loc-nuts that had to be removed in order to lift the engine cover for greater access.

During NAVSEC Norfolk's technical evaluation it was planned also, to test the boat in surf-rescue situations under controlled and instrumented conditions. Unfortunately, this was not possible because of time and scheduling commitments which called for delivering the boat to an operational unit in the Thirteenth Coast Guard District for evaluation on the coast of Oregon's entrance bar surf conditions during the 1973 summer boating season.

The tests at Norfolk were useful not only in measuring and documenting the MRBX's technical particulars, but also by affording an opportunity to identify some items in the boat, as built, which needed correction before delivering it to an operational unit. In general the technical evaluation indicated that MRBX could be expected to perform very satisfactorily in service. No major faults or deficiencies were

discovered. The boat gave a soft ride in a seaway and had low accelerations at the helmsman's station. It was, however, 1775 pounds heavier than the design weight estimate. Also, two control or handling problems were discovered. Directional control in backing was difficult and unpredictable in that once the bow started to swing it could not be stopped irrespective of speed or helm position. This phenomena is not uncommon in pump jet-propelled boats which have no rudder, skeg or vertical keel. Secondly, the boat had a tendency to fall off to port or starboard as it overtook a wave in a following sea. This action is also fairly common to many boats.

2.2 Post-Test Modifications

In March 1973, MRBX entered the Coast Guard Base, Portsmouth, Virginia shops for correction of the faults that had been noted during the technical evaluation period. We were fortunate in that Captain R. W. WITTER[1] was Commanding Officer of the base and we were able to take advantage of his personal interest and past experience in effecting the changes and modifications to improve MRBX.

The changes were aimed principally towards reduction in weight, improving visibility, improving directional control, improving and simplifying details of arrangement and operator convenience. The principal items included:

a. Removal of all around rubber gunwale fender (350 lbs.).

b. Lowering of forward and side spray shields to improve visibility and save weight.

c. Modifications to engine box and survivor's compartment door to facilitate access.

d. Replacing two lever throttle and direction control with single lever.

e. Installed a "backing" skeg at the forefoot to provide maneuvering control.

f. Relocating radio from alongside helmsman at the side to a recess in the control console.

g. Replacing 125 engine cover bolts with 10 latches.

h. Removing safety hazards from the cockpit.

i. Eliminating aft compartment hatches.

j. Changing scuppers to freeing ports to improve cockpit drainage.

A net weight reduction of 835 pounds was achieved by these modifications. Figure 7 shows MRBX as modified in 1973.

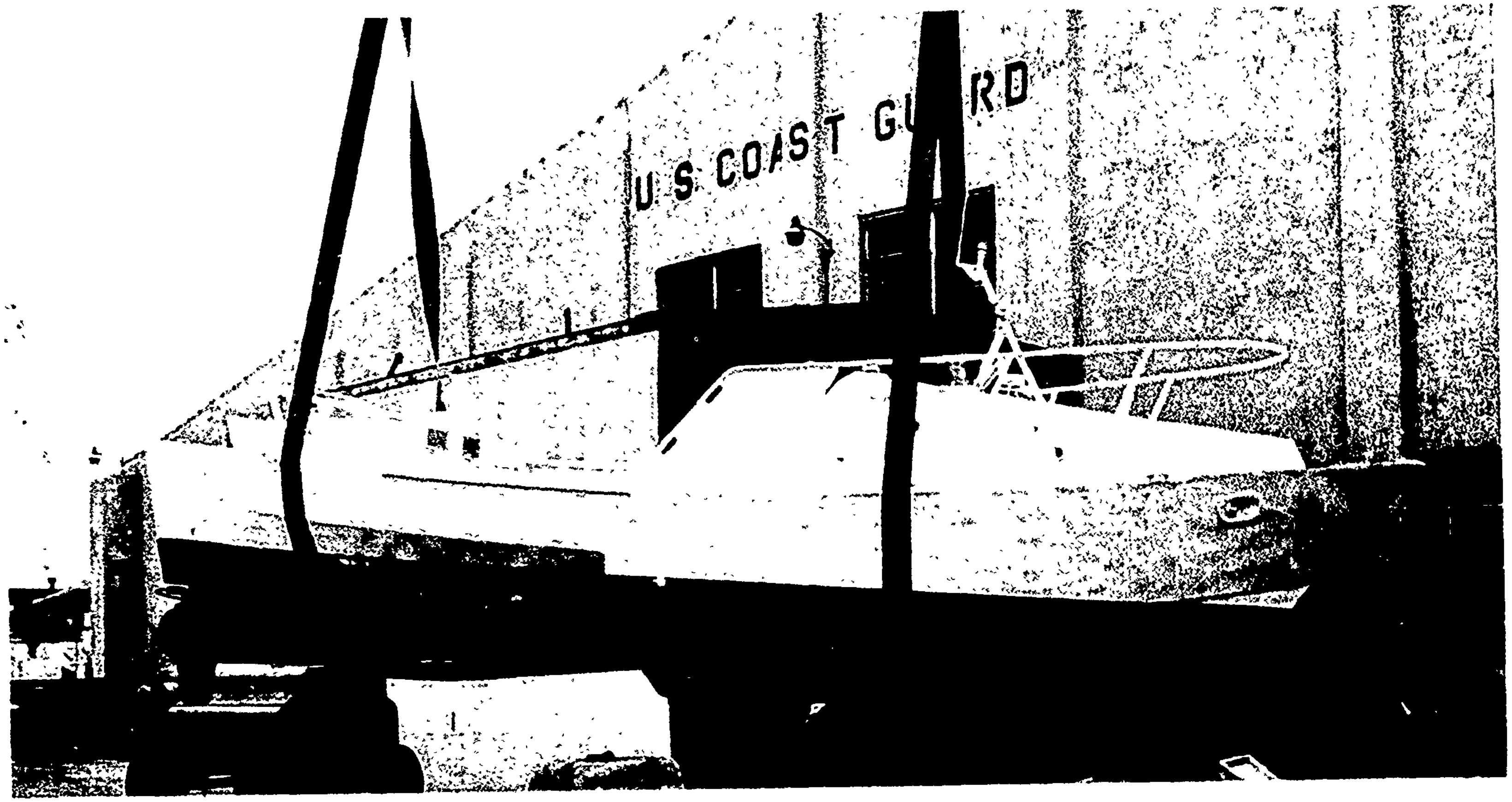


FIGURE 7. MRBX as modified in 1973

In April 1972, with modifications completed, MRBX was driven to Oregon Inlet, North Carolina for post modification shakedown and surf tests before being assigned to an operational unit. The boat's full speed at this time with optimum foil adjustment was 24 knots.

2.3 Operational Evaluation - 1973 Summer Season

MRBX was delivered to U. S. Coast Guard Station, Tillamook Bay, Oregon in early May 1973. The first two weeks were spent in familiarizing the station's boat crews with the differences and operation peculiarities of the boat. The boat was first given smooth water checkouts followed by open sea and then progressively more severe surf conditions. On the Tillamook entrance bar, eight to ten feet of surf is considered to be a mild condition. Initially, the station personnel held reservations on MRBX's capability to operate in these conditions until after a two-hour period of placing the oboat in every conceivable attitude and speed in the surf when a 10-14 foot wave caught the boat broadside. MRBX rolled 90 degrees and then recovered. This convinced the crew of MRBX's surf capability and survivability.

During the 1973 summer season, MRBX was operated from Coast Guard Moorings, Nehalem River, Oregon. The Nehalem River bar is one of several on the Pacific Northwest Coast where the water is too shallow to accept a 44-foot motor lifeboat and where bar conditions require a boat with better surf capability than are available with our 30 to 40-foot utility boats.

Operational evaluation score or test sheets were solicited from everyone who had occasion to operate or ride in the boat. These were used as a basis for further refining the design and subsequent arrangement modifications. A summary of evaluations appears in Table 4.

The summer 1973 operation was generally quite satisfactory, and it was concluded that MRBX's overall suitability for its intended service was good. Surf handling and seaworthiness were considered excellent, but three items were identified as major and needed prompt correction.

First, it was discovered that in shallow water operations, sand, pebbles and stones could be stirred up by the propulsion pump discharge and could cause the jet's directional gate to jam in the closed position. In four instances while operating in shallow water, the control gate jammed in the "astern" position. The last such jamming occurred while MRBX was near a private power craft and resulted in MRBX's hull being punctured. The boat flooded and grounded. Investigation of this problem with the pump jet manufacturer (Jacuzzi Brothers, Inc.) resulted in corrective action to the mechanism by providing greater clearance for moving parts and less area for material to accumulate.

Second, in down sea running with MRBX overtaking the waves, the boat was sluggish and tended to broach (principally to starboard). The reasons for this problem were thought to be a combination of low relative speed for the foil causing the boat to fall off plane and the lack of adequate vertical control surfaces (rudder, skegs, etc.) resulting in poorer directional control than exists in conventional boats. Several modifications to the foil were attempted on the MRBX to improve the down sea characteristics, but the most effective remedy consisted of shifting the LCG of the craft further aft.

Table 4. Evaluation summary.

OPERATIONAL AVAILABILITY

(1) HOURS AVAILABLE FOR OPERATION 2,034.2

(2) HOURS NOT AVAILABLE DUE TO MECHANICAL FAILURE 459.7

(3) HOURS NOT AVAILABLE DUE TO HULL FAILURE 0

(4) HOURS NOT AVAILABLE DUE TO ROUTINE MAINTENANCE 0

E - EXCEL
G - GOOD
S - SAT
P - POOR

PERFORMANCE RATINGS	E	G	S	P	E	G	S	P
A. PERFORMANCE								
(a) SPEED		2	2			14	4	
(b) HIGH SPEED MANEUVERABILITY		3	1		1	13	4	
(c) LOW SPEED MANEUVERABILITY			4			' 2	16	
(d) DIRECTIONAL STABILITY AHEAD		3	1		1	11	4	2
(e) RETRIEVAL OF SURVIVORS		4			3	14	1	
(f) TOWING			3			7	7	
(g) SURF HANDLING	2	2			6	11	1	
(h) SEAWORTHINESS		4			3	13	2	
(i) BACKING ABILITY		3	1			7	11	
(j) EQUIPMENT SUITABILITY		3	1			6	10	2
(k) ENGINE/HELM CONTROLS		3	1			12	3	3
(l) OVERALL SUITABILITY FOR SERVICE		4				15	3	1
B. HUMAN FACTORS								
(a) VISIBILITY	4				7	10	1	
(b) LOCATION OF CONTROLS		4			1	13	4	
(c) LOCATION OF ELECTRONIC GEAR		3		1		9	4	5
(d) SUITABILITY OF HARNESSES		4			1	9	7	
(e) SUITABILITY OF SURVIVORS' COMPARTMENT				3		3	8	7
(f) NOISE LEVEL		4				12	6	
SUMMARY OF MRBX EVALUATIONS MAY - AUG 73	STATION ____				CREW MEMBER ____			

Finally, it was learned that General Motors Corporation had discontinued production of their Model 8V53 engine. A different engine would have to be selected for production order boats.

2.4 Following Sea Model Tests

One of the three major discrepancies in the MRBX, brought to light as a result of the 1973 SAR season operational evaluation, was the craft's tendency to broach in a down sea running condition overtaking the waves. This lack of directional stability was naturally disconcerting to all the coxswains. From the outset of the MRBX operational evaluation, it was believed that control surfaces should be installed on the craft to increase its directional stability, but a counter consideration was that of retaining the shallow water capability of the craft. For example, a rudder would increase the craft's directional stability but would also increase the draft. Some believed the orbital velocity pattern of the water particles in a wave caused a loss of foil lift as the craft overtook a wave, thus allowing the stern to fall and vessel speed to decrease. Once this occurred the wave would overtake the boat and the tendency to broach would be increased.

To identify the problems involved, the Davidson Laboratory at Stevens Institute of Technology was contracted in December 1973 to conduct following sea model tests and investigate some of the features affecting the tendency of MRBX to broach, with particular emphasis on finding a practical solution.

Broaching liability is known or suspected of being influenced by a variety of hull form features including beam-draft ratio, length-beam ratio, fineness of ends, section shape forward and aft, and trim. Generally, those features which improve a vessel's calm water directional stability also reduce the liability to broach when running in following or oblique seas. Hopefully a solution, if found, would be simple in nature and would not require a modification of the hull lines, drastic surgery to the craft or the installation of a control system for variable lift on the foil.

Although to properly model the complete behavior of a broaching craft, a self-propelled free model with a control system simulating the helmsman at the wheel would be necessary, budgetary constraints limited our investigation to a more modest effort. A 1:5.5 scale model with 5 degrees of freedom (free to roll, pitch, heave, surge and yaw, but constrained in sway) was tested in calm water and following seas having a wavelength of twice the boat's length. This was to duplicate the MRBX's tendency to broach and establish the constant towing force required for both correct running speed (20 knots) and correct hump speed (12 to 14 knots).

Once the full-scale conditions were duplicated, progressively steeper waves from wave height to wave length ratio of 1:4 to 1:2 were modeled. In conjunction with the steeper waves, various solutions were investigated that included the installation of a vertical fin (shark fins) on each tip of the foil to, hopefully, increase directional stability through increased lateral surface area, the attachment of wedges to the aft portion of the planing forebody changing the running trim of the boat, and longitudinal shifts in the craft's center of gravity changing both the static and dynamic trim of the boat.

To quantitatively analyze the data, the amplitude of a characteristic yaw excursion was plotted as a function of wave height to wave length ratio and, as can be seen in Figure 8, the effect of shifting the craft's LCG is apparent. Small yaw excursions may in general be considered as a low tendency to broach as compared with large yaw excursions. An LCG of 22 inches aft of the hull step resulted in a decrease in the tendency to broach as compared with LCG positions of 10 inches and 31 inches aft of the step.

Based on the results of the tests conducted at Stevens Institute on a variety of modifications of the MRBX it was concluded that the directional stability and broaching tendencies appeared to be most affected by a load distribution between the planing forebody and the hydrofoil supported stern. Modifications of the craft's attitude by external hydrodynamic devices such as trim flaps on the planing forebody without adjusting the longitudinal position of the center of gravity did not have significant effect on the directional stability. As a result it was concluded that a shift in the longitudinal center of gravity aft about 12 inches (full size) on the prototype would improve the following sea broaching tendency without appreciably increasing the hull resistance. The installation of the vertical fins on the foil tips did not help in following sea performance.

During the February 1974 yard availability to perform post-season modifications and re-engining of the MRBX, the longitudinal center of gravity was shifted aft as far as possible in order to improve the directional stability of the boat.

2.5 Post 1973 Season Modifications and Re-Engining

In addition to the three major areas for improvement , two other minor items were noted during the 1973 summer season operational evaluation. Specifically, the ultimate user of the craft felt that the 75-mile range was too short and that the location of the batteries, with the protruding battery box cover underneath the feet of the crew members, was undesirable. Fortunately, accomplishment of both improvements would move the LCG of the craft aft as recommended by the Stevens Institute model test studies. This increasing of the range, available only through increasing fuel tank capacity, had the disadvantage of adding more weight to an already overweight craft. However, it was decided that a doubling of the range was of more benefit to overall mission performance than a small loss in speed. Preliminary calculations showed the overall effect of the battery relocation and a relocation and doubling of the fuel tank to be a shift in the LCG aft by approximately six inches. This was in fact realized after the modifications were accomplished. In addition, these studies showed that no detrimental effects regarding the self-righting capability would be encountered by the longitudinal weight shifts. Figure 9 shows the "as built" configuration, and the relocation of the battery and fuel configuration.

The major problem posed by the discontinued GM 8V53 required that a new engine would have to be selected for use in production MRB's. All available engines with similar horsepower were too heavy for the weight-sensitive craft. In addition, rpm matching problems between the pump jet and the engine, plus engine size restrictions, compounded the problem.

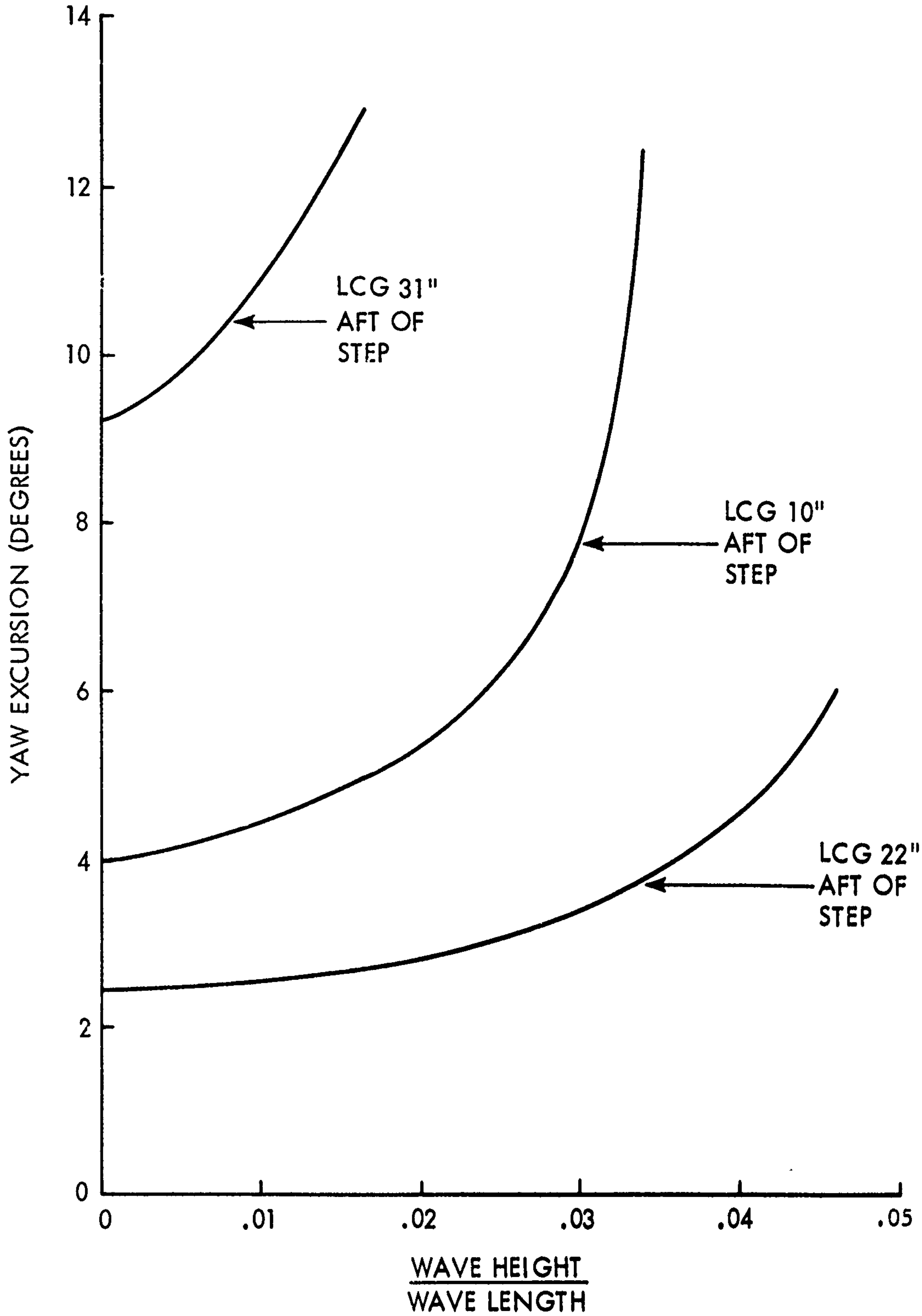
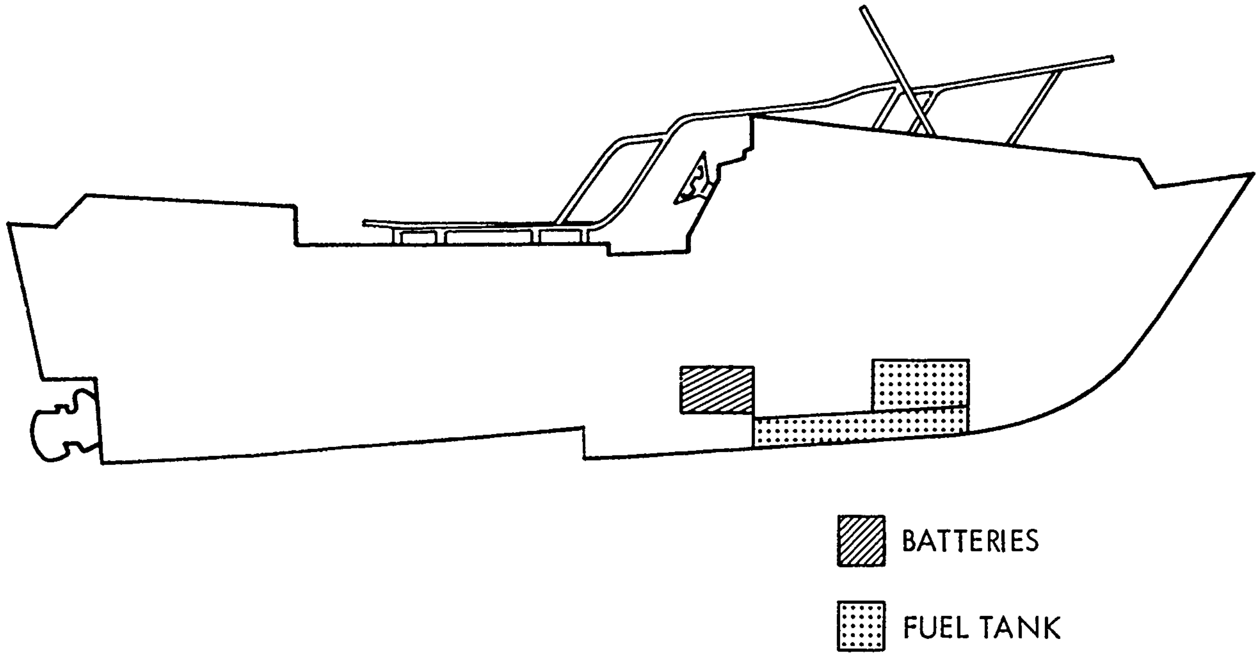


Figure 8. Broaching Liability



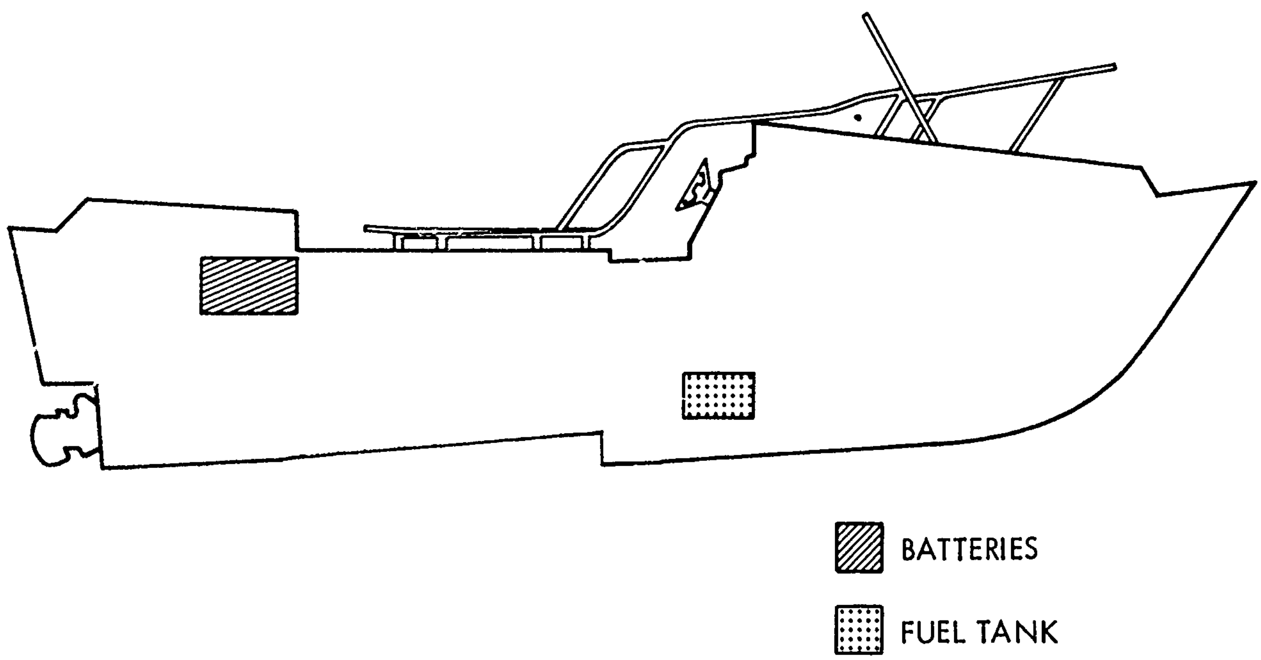


FIGURE 9 - TANK AND BATTERY LOCATIONS

Complete engine feasibility study details are discussed later, but the conclusion was that a GM 6V53 should be installed. Inasmuch as the basic engine configuration remained the same, with the only difference being a loss in overall engine length, the re-engining proceeded without incident except for usual installation problems.

Following the modifications and re-engining, the MRBX underwent trials and adjustments at Yaquina Bay Coast Guard Station, Newport, Oregon.

2.6 Post-Availability Trials and Adjustments

Following the February 1974 yard availability, trials were conducted to evaluate the following:

a. The determination of the optimum angle of attack for the foil with the craft's new LCG:

b. Determination of the seakeeping effects of relocating the LCG further aft; and

c. The suitability of the General Motors 6V53 engine and proper pump impeller for production MRB's.

With regard to the optimum angle of attack, it was determined early in the trial period that maximum speed was achieved with the highest foil angle of attack. Unfortunately, high angles of attack, in addition to increasing the speed, also cause the stern to ride too high, thereby reducing the running trim of the craft. This has two adverse effects:

(1) As the trim by the bow is too great, the bow skeg, installed for backing directional stability, becomes totally immersed and inhibits predictable turning tin the ahead mode; and

(2) With the stern riding too high, the jet pump suction ventilates on a turn causing a loss of thrust, uncontrollable maneuverability and loss of speed.

Foil adjustment procedure therefore required only the establishment of the point of acceptable maneuverability at the highest foil angle of attack.

Theorizing prior to the Stevens' model testing on the MRBX broaching problem and foil adjustment led to a study at the CG R&DC to determine whether a different foil design might generate more lift in the hump region of operation. Hopefully, increased lift in this region would delay "falling off plane" in craft deceleration such as occurs in following sea running while overtaking a wave. In addition, it was also speculated that the original foil furnished with the MRBX generated too much lift at full speed and therefore required a large negative angle of attack in order to provide the proper running trim of the craft. As a result of this study, a NACA 64_1-412 foil was fabricated and tested. Additionally, the original foil (NACA 4412) was shortened to a span of 72 inches to reduce the generated lift, thereby allowing a less negative angle of attack for proper craft trim.

The results of these foil optimization tests for both the shortened original foil and the new test foil are shown in Figure 10 where it can be seen that the angle of attack for the onset of unacceptable maneuverability appear at the high angle of attack for each foil. For the original foil this was α greater than -1.5° while the test foil was unacceptable at α greater than 0°. It should be remembered here that α is relative to the baseline and in a running condition the effective angle of attack seen by the foil includes the running trim of the craft (approximately 4°) thus providing an effective positive angle of attack during operation. Figure 10 also shows that the angle of attack of the test foil has a relatively minimal effect on the speed of the craft while the angle of attack of the original foil has a marked effect on craft speed.

As a result of this foil optimization testing and seakeeping tests at Yaquina Bay, it was decided that the test foil did not provide sufficient speed for the craft nor significantly improved performance over the original foil in a following sea. The original foil shortened to a span of 84 inches, was therefore selected to be retained for production MRB's.

After initial alignment and rpm adjustment problems during the early portion of the test and evaluation had been eliminated, the GM 6V53 engine with N55 injectors was deemed satisfactory since calm water speeds in excess of 20 knots were achieved without overloading the engine. Using impeller selection curves furnished by the pump jet manufacturer, three impellers (Class A, C and G) for the 14YJ pump were selected for testing. The Class G impeller provided the best engine loading at design engine rpm (2800), so the GM 6V53 combined with the G impeller in the jet pump were recommended for production MRB's.

Throughout the engine the foil tests, following sea running was conducted at various speeds and in various wavelengths. It was concluded that the tendency to broach in a following sea had been greatly reduced as a result of shifting the LCG further aft. With these improvements normal boat handling techniques were adequate while handling the MRBX in the surf and following sea conditions. Figures 11 through 13 show the MRBX on a typical training exercise in the surf off Yaquina Bay.

Following these trials and adjustments at Yaquina Bay, the MRBX was moved to Coast Guard Station Tillamook as an operational craft for the 1974 summer season.

2.7 Operational Evaluation - 1974 Summer Season

The 1974 summer operational season found MRBX again at Nehalem River, Oregon, where her high speed, good surf capability and shallow draft were most welcome. Operations were uneventful except for one major incident. At one time during normal operations, the MRBX was rolled over in breakers on the entrance bar. Once again she righted herself with engine still operating and was brought back by her crew safely and without damage.

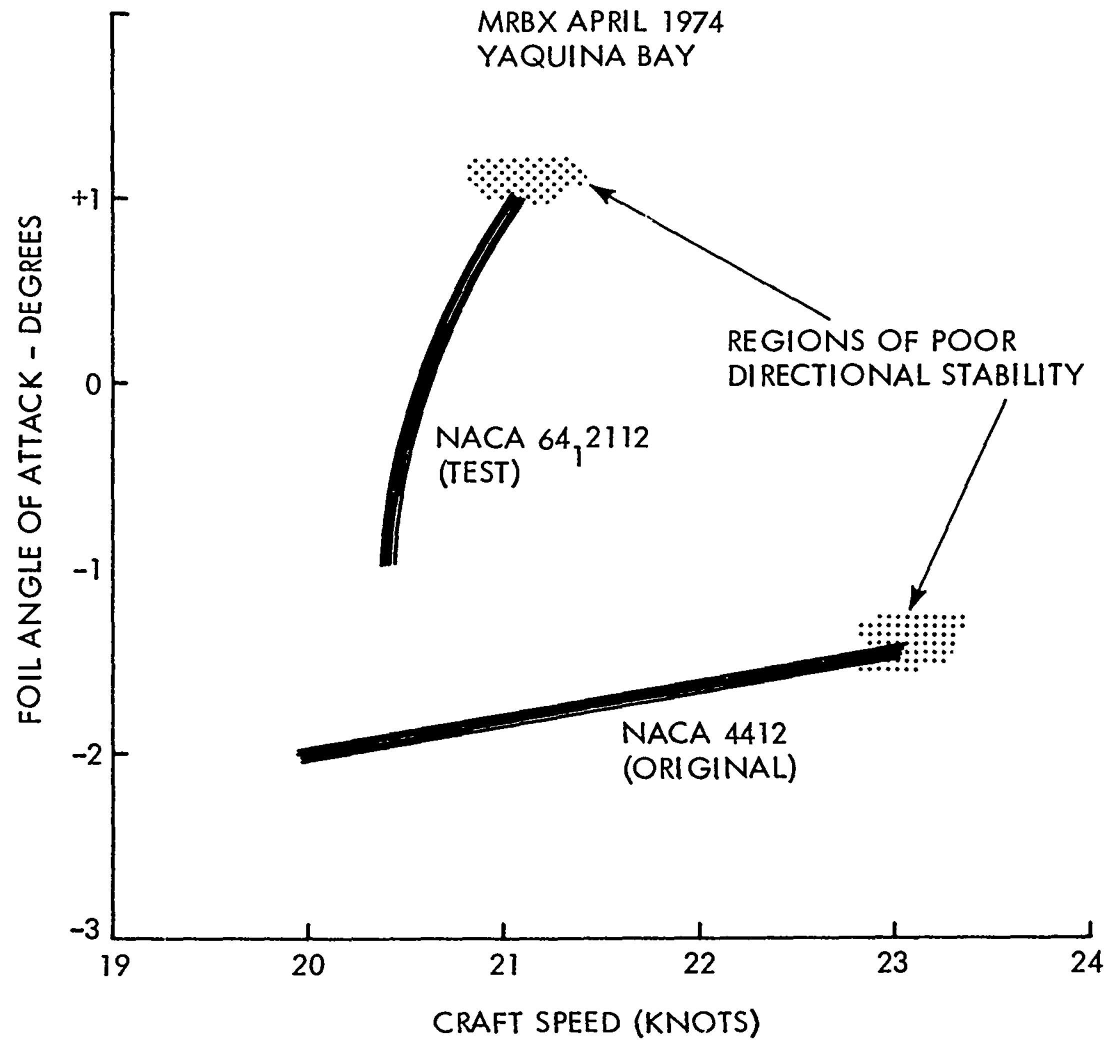


FIGURE 10 - CRAFT SPEED VERSUS ANGLE OF ATTACK FOR ORIGINAL AND TEST FOILS

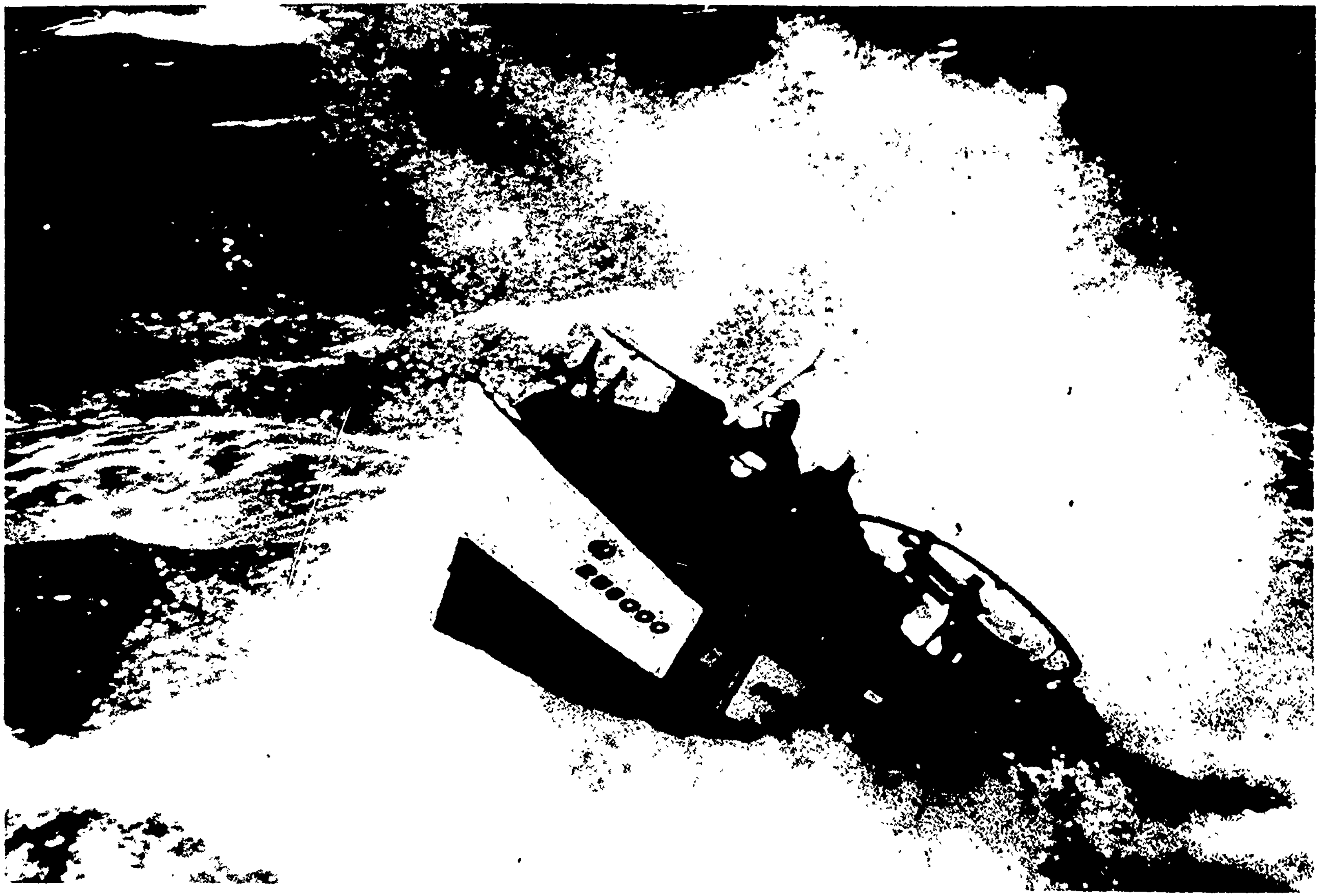


FIGURE 11 - MRBX Beam to a Surf Line

FIGURE 12. MRBX in Surf Off Yaquina Bay, Oregon

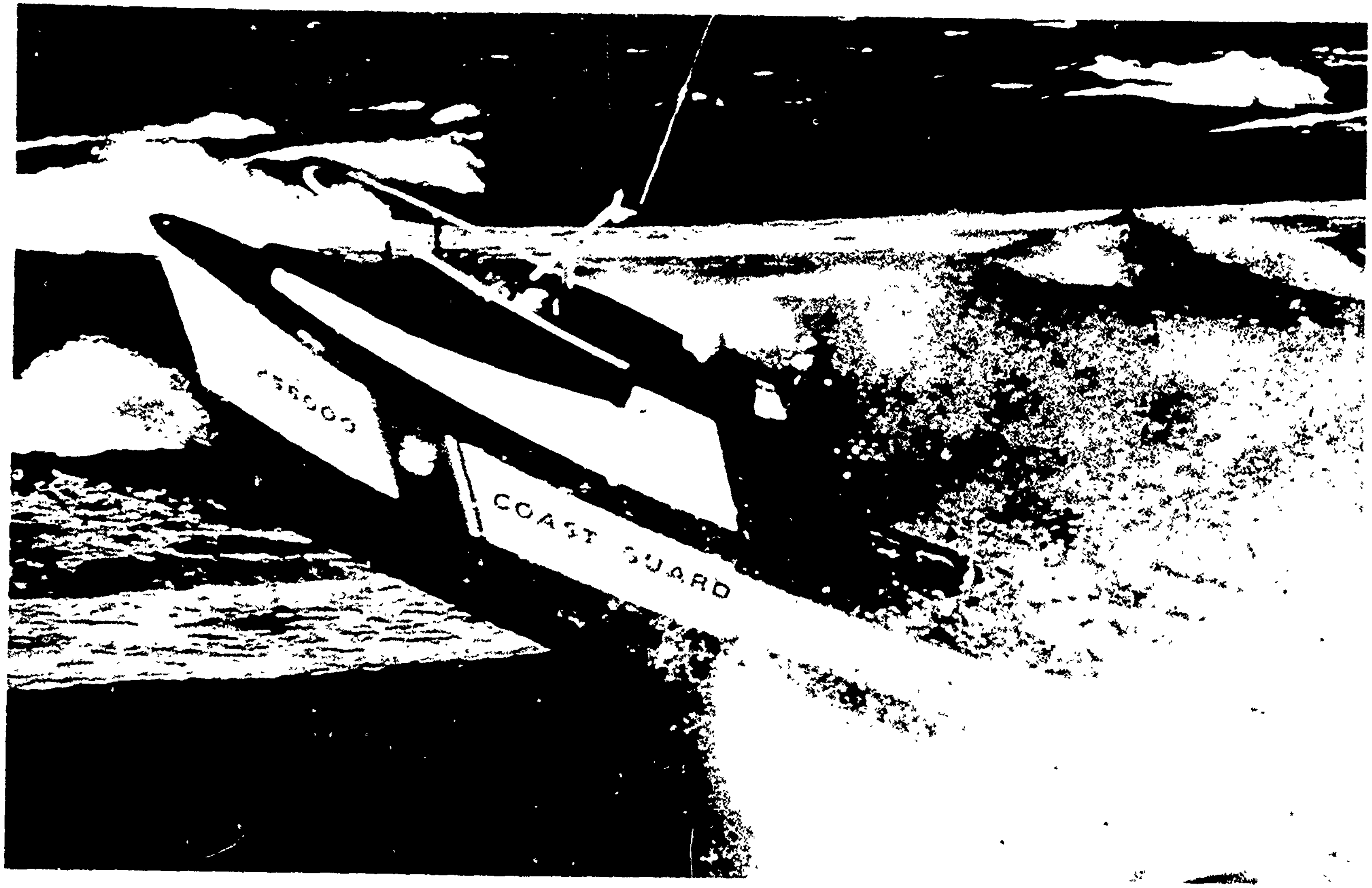


FIGURE 13. MRBX Transiting the Surf Line

This season saw MRBX operating over 360 hours without an engine-related problem. Some pump jet maintenance was required, but by and large the boat has proven her ability to operate in conditions approaching her design points without difficulty. The consensus of opinion of operating personnel during the season was most favorable, and even with the smaller horsepower engine (220 vice 280 hp) the boat:

Responded quickly in the surf: 10 to 12 seconds from dead in the water to full plane;

Had adequate speed to outrun or maneuver in breakers;

Was adequate for towing operations.

Despite the fact that the GM 6V53 (220 hp) engine was deemed acceptable for MRBX propulsion, it was decided to investigate the improved performance potential of the craft with the lightweight GM 6V53T1 (280 hp) engine in the following 1975 SAR season.

2.8 Post-1974 Season Modifications; Re-Engining

Following the 1974 summer SAR season, a GM 6V53T1 engine was procured from Stewart and Stevenson, Houston, Texas, and installed in MRBX during the February 1975 yard availability. As discussed previously, and in Section 3.2 - Power Plant Selection - it was hoped that the maximum potential performance of the MRBX hull would be realized with this lightweight (1800 lbs), high-powered (300 hp max.) turbo-charged engine.

In addition to the re-engining of MRBX, several slight modifications were also performed during this availability:

Since the installed GM 6V53T1 engine is wider than the basic GM 6V53 engine due to the location of the turbocharger, a new engine hatch cover was designed and installed. This new hatch cover required a slight reduction in portside cockpit space, however, sufficient clearance remained between the hatch cover and port gunwale to permit ready personnel access, so this was deemed acceptable. (Production 6V53T1 engines can be configured with the turbocharger directly aft so no enlarged hatch cover is necessary in production craft.)

Removable cockpit deck grating was installed in the craft to provide sure footing of the MRBX crew and to compensate for the unavoidable wet cockpit deck. Figure 14 illustrates the new engine installation and a section of deck grating in the cockpit.

The jet pump deflector gate control linkage was eliminated in favor of direct coupling of the Morse control cable to reduce the possibility of failure and to eliminate excessive control system friction. Figure 15 illustrates this improved arrangement. Brief performance trials following the installation of the 6V53T1 engine were most impressive. In all conditions of loading, MRBX achieved speeds in excess of 24 knots and halved the time required from dead in the

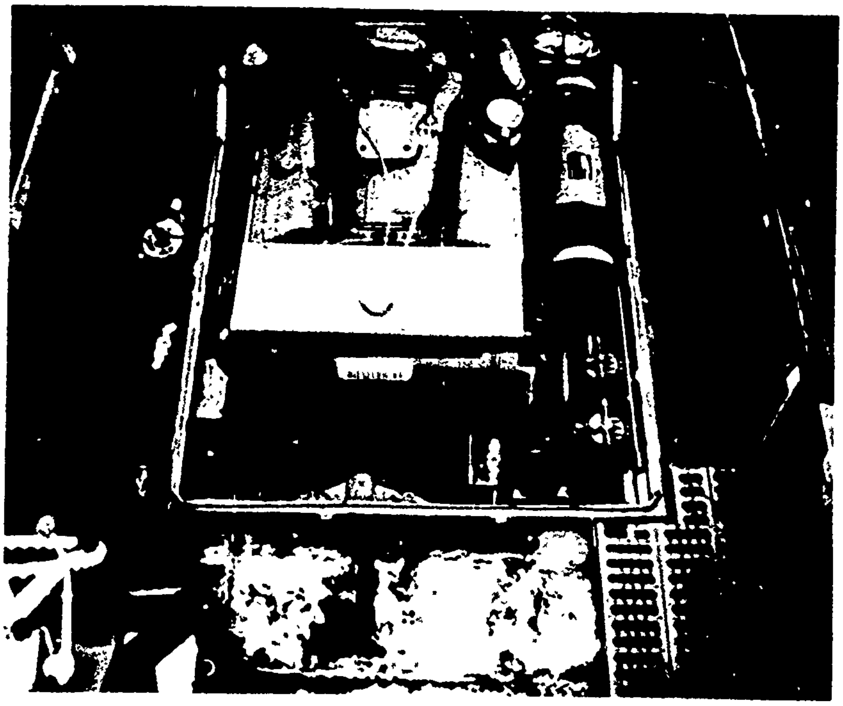


FIGURE 14. GM6V53T1 Engine Installation and
Section of Installed Cockpit Deck Grating

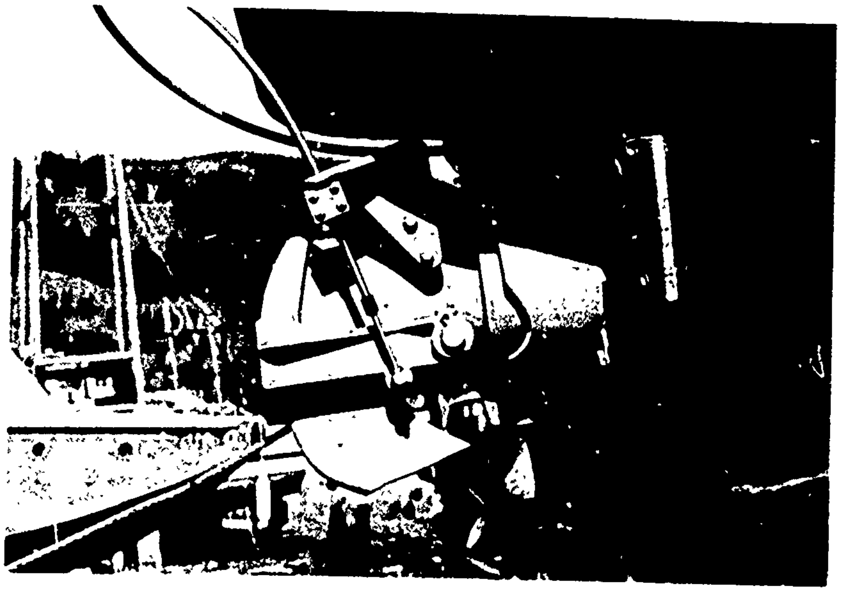


FIGURE 15. Modified Jet-Pump Deflector Cable Control

water to full plane condition. In the surf, the new engine gave the craft outstanding acceleration. Table 5 summarizes the MRBX's performance with the basic GM 6V53 and the GM 6V53T1.

TABLE 5

Engine				Performance	
Model	HP	WT	Max. Speed	Time to Plane	Reserve Power
6V53	220	1700#	20 kts	15 secs.	Minimum
6V53T1	300	1800#	24 kts	7 secs.	Ample

In addition to performance trials, noise level readings were taken on the 6V53 and the 6V53T1 engines as installed in MRBX. As can be seen in Figure 16, no significant difference between the two engines exists.

During the performance trials following the installation of the turbocharged engine, two engine failures occurred. The first was a severe case of overheating due to a loss of fresh water in the engine cooling system, and the second was a turbocharger failure due to a blockage of oil supply to the turbocharger bearings. In the case of the overheating, the engine was rebuilt with new bearings, liners, pistons, connecting rods and seals, and for the second failure only the turbocharger was rebuilt. Since the GM 6V53T1 engine is a "high performance" engine, some decrease in reliability and some increase in maintenance can be expected. The question remaining at this point is "how much." Both engine failures above are the result of personnel carelessness and should be avoidable in the future. For the 1975 summer SAR season, Commander, Thirteenth Coast Guard District will have both operational and technical control of MRBX and will therefore be able to more accurately assess the longer term reliability and maintainability of the 6V53T1 engine as installed in this craft.

As regards craft performance, however, it is recommended that production MRB's should have a nominal 300 hp, 1800 pound engine to realize the full speed and maneuvering potential of the hull design. If the GM 6V53T1 engine fails to provide acceptable reliability, the Caterpillar 3208T is another engine alternative.

3.0 PRODUCTION MOTOR RESCUE BOAT (MRB) DESIGN

3.1 MRB Hull Structure

MRBX has proven in service the ability to perform to her basic design objectives. In translating the experimental MRBX to a production motor rescue boat (MRB) it became incumbent upon the CG R&DC to review all aspects of the original craft in terms of reducing costs.

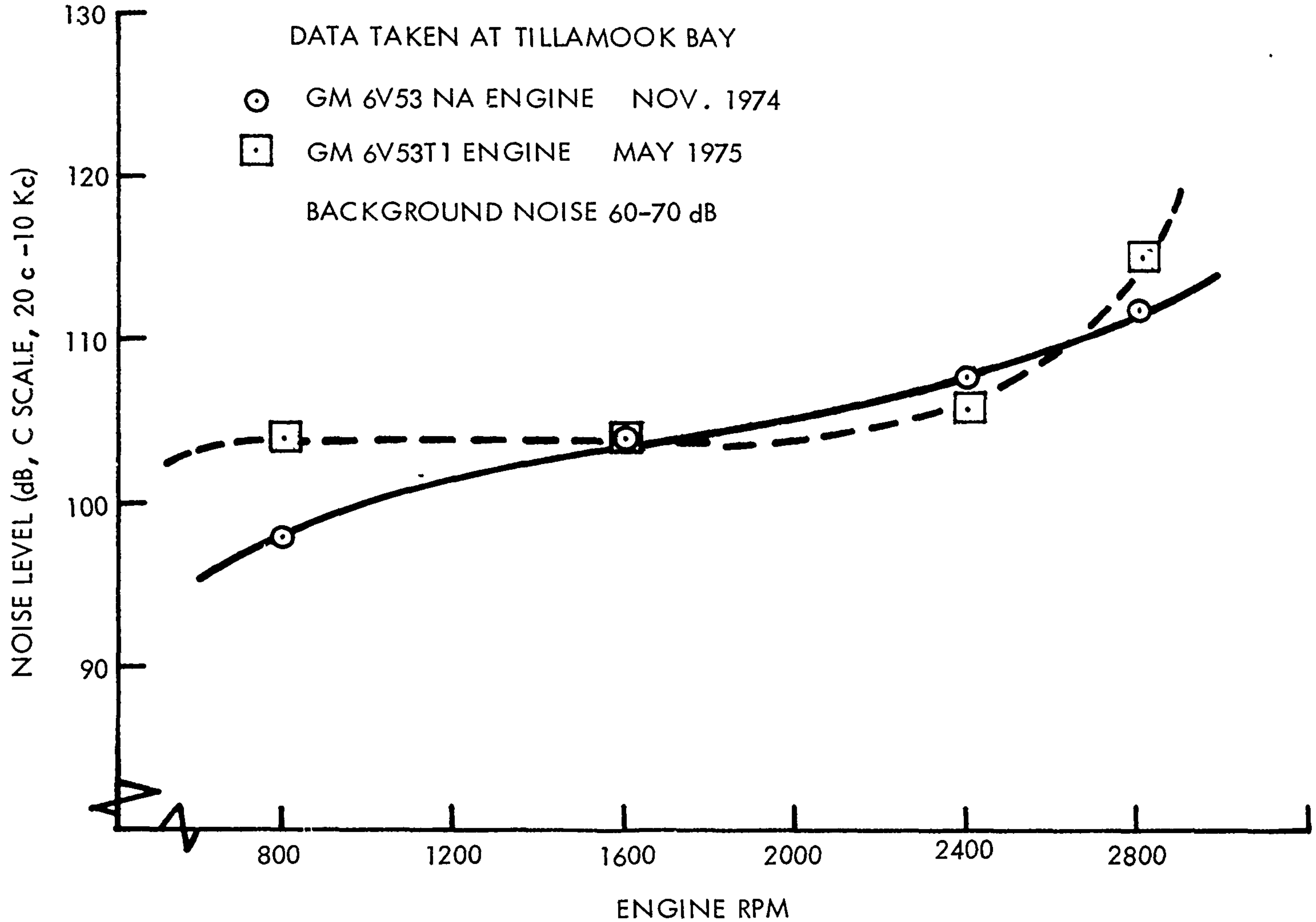


FIGURE 16 MRBX ENGINE NOISE LEVELS

One of the first areas which appeared to be a candidate for cost reduction was the hull structure. Whereas the MRBX with its egg-crate type construction was undoubtedly strong enough, it also was costly to fabricate and difficult to keep free of unsightly welding distortions.

Accordingly, a structural design review was conducted and a redesign was authorized with the objective of reducing hull fabrication, fitting and welding costs as much as 15 percent without degradation of hull strength below allowable safe limits.

The new MRB hull structure was designed to the following criteria:

a. Use of Heller and Jasper[5] design method.

b. Acceleration of 2.5g at the center of gravity.

c. Use of 5086-H32 aluminum alloy having an "as welded" allowable stress in yield of 19 ksi.

d. Permissible permanent set of .005b where b is the panel width.

e. Minimum hull plate thickness of 0.125 inches.

It is expected that the new hull structure will allow the design objectives to be achieved and, together with a carefully adhered to welding sequence, will result in a fair, aesthetically attractive finished hull.

3.2 Power Plant Selection

Because the General Motors Model 8V53 diesel originally installed in the MRBX was no longer in production, and because the major purpose of the test and evaluation was to determine the MRBX's suitability for production, an engine for future MRB's had to be located, installed and tested. The availability of American-manufactured high speed, lightweight diesel engines suitable for the MRBX is severely limited. Therefore, it was realized from the outset that a compromise in performance, reliability or maintenance might have to be accepted upon re-engining the craft. Understanding this, a feasibility study was undertaken to determine which engine should be recommended for production MRB's.

Reviewing the original design objectives of the MRBX, it was decided that under no circumstances should the calm water speed at normal full load displacement be allowed to fall below 20 knots. A level of desired reliability is rather abstract and is a less tangible item than speed to quantify, so it was addressed only in general terms. For example, a turbocharged engine was considered less reliable than a naturally aspirated version. Quantification of levels of expected maintenance for an engine are influenced by the power demanded and reliability desired and can be best described as mean time between overhauls (MTBO). For MRBX the minimal acceptable MTBO was set at 500 hours. This would provide for a full SAR season's operation and permit overhauls to be scheduled during off season periods.

All in all, however, the candidate engines had to be: (1) available (i.e., a production engine on the market); (2) the proper size and weight; and (3) within the horsepower and rpm range consistent with the specified general requirements of power, reliability and maintenance. The specific characteristics of the candidate engines are listed in Table 6. As noted in the remarks column, only three engines were considered suitable based upon engine rpm factors. Of these three engines, only one was immediately available--the GM 6V53. The GM 6V53T1 would be available in January 1975, and the Caterpillar 3208T was projected for January 1976.

In addition, the GM 6V53 was attractive for several other reasons. First, the engine was well-known to both our operators and mechanics as it is installed in a number of our 44-foot motor life boats. Secondly, for the same reason, spare parts would present no problems. Finally, it would provide a measure of how well MRBX would perform fitted with an engine which was at the lower limit of the acceptable power range for the boat.

In Figure 17 we have plotted speed versus MRBX resistance for various boat weights and superimposed curves of engine horsepower. The three engines under consideration and the original engine are shown on the graph.

Figure 18 shows the impeller selection technique used with the Jacuzzi 14YJ pump jet. As can be seen, Jacuzzi recommends Class G impeller with the 6V53 engine. During our trials and adjustments following the re-engining of the MRBX with the 6V53, we found, as expected, that the G impeller out-performed both the A and C types, both of which caused the engine to run in a somewhat overloaded condition. With the G impeller, the pump jet could absorb 210 horsepower at 2800 rpm from the 6V53, which provided calm water craft speeds in excess of 20 knots in all conditions of loading. With the GM 6V53T1 engine, an A impeller is necessary to absorb all available engine horsepower.

4.0 CONCLUSIONS

Three years of technical and operational evaluations coupled with modifications and model testing have resulted in transforming the experimental motor rescue boat to a prototype for a production motor rescue boat. MRBX has not only survived the rigors of actual operations but also has performed most capably over a two-season span without the benefit of specially trained operators or technicians.

The MRBX type design fulfills the need for a high speed personnel rescue boat which can operate in 8 to 10 feet of plunging surf, as well as in the shallowest of bays and rivers. This boat can satisfy many of the operational missions now performed by 44-foot motor life boats at considerably less cost in purchase and operating expense. Thus, the MRB is a fully acceptable boat for many Coast Guard missions and has proven itself by having successfully satisfied an operational boat need for two full years in the rigorous and demanding conditions prevalent on the Northwest Coast entrance bars.

ENGINE	ENG WT CRAFT WT 100% F.O. FULL LOAD CONDITION	SIZE L W M	HP	RPM	REMARKS
GM 8V53	2423 6900 7200	56 40 33	260	2800	ORIGINAL ENGINE OUT OF PRODUCTION
GM 6V53	1830 6307 6607	46 40 40	216	2800	FEASIBLE AND SELECTED FOR 1974 SEASON TEST
GM 6V53TI	2024 6501 6801	58 44 39	280	2800	AVAILABLE JAN 75 SELECTED FOR 1975 SEASON TEST
GM 6V92	1960 6437 6737	41 39 47	302	2100	RPM TOO LOW
GM 6V71	2570 7047 7347	55 44 45	240	2300	RPM TOO LOW
CUMMINS 555	1850 6327 6627	48 35 33	240	3300	RPM TOO HIGH
CUMMINS 903	2300 6777 7077	56 40 38	320	2600	RPM TOO LOW
CATERPILLAR 3208T	2013 6490 6700	54 38 36	275	2800	NOT AVAILABLE UNTIL JAN 1976

Table 6. Engine characteristics chart.

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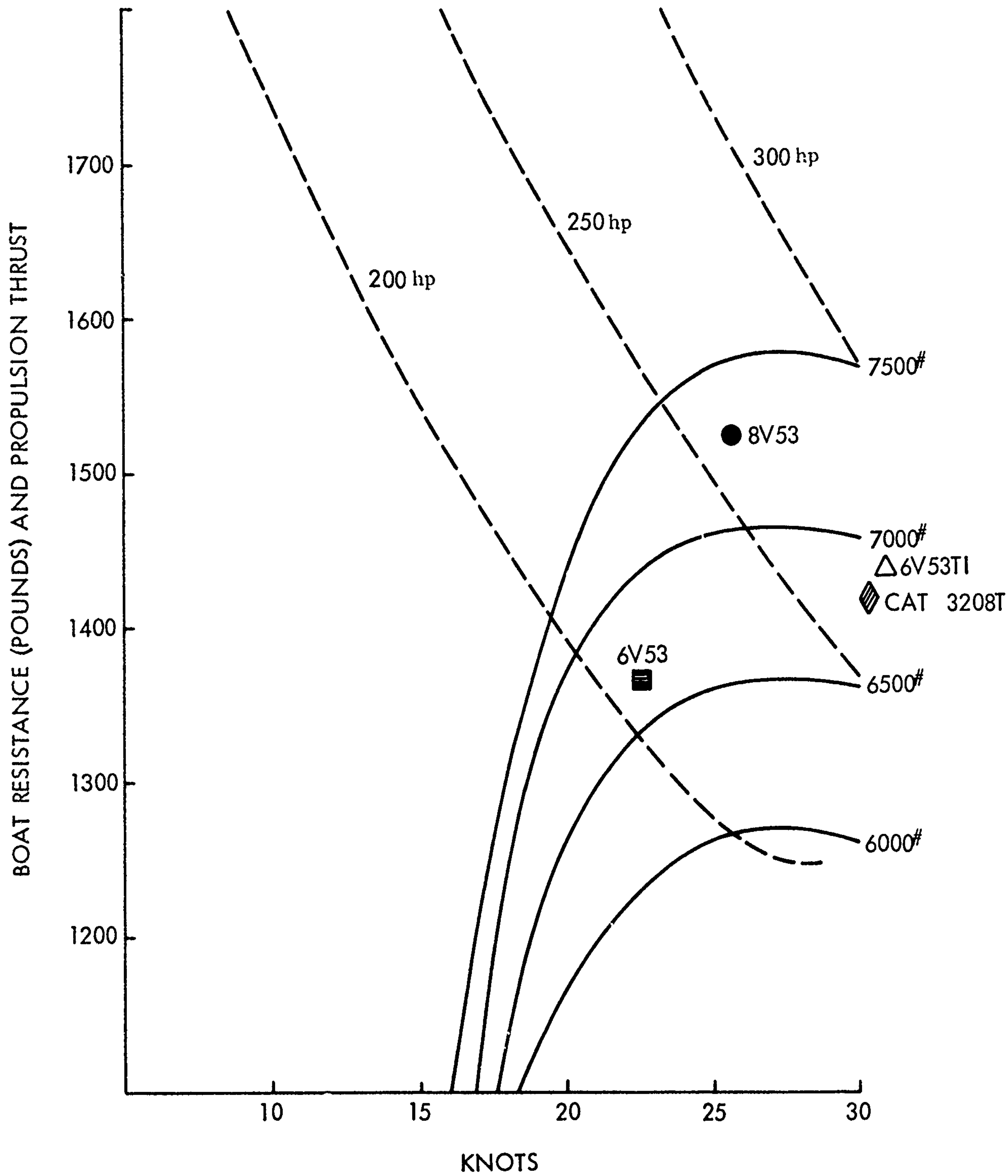

Figure 17. Approximated MRBX drag versus speed curves for displacement of 6000# to 7500# with horsepower (thrust) curves superimposed.

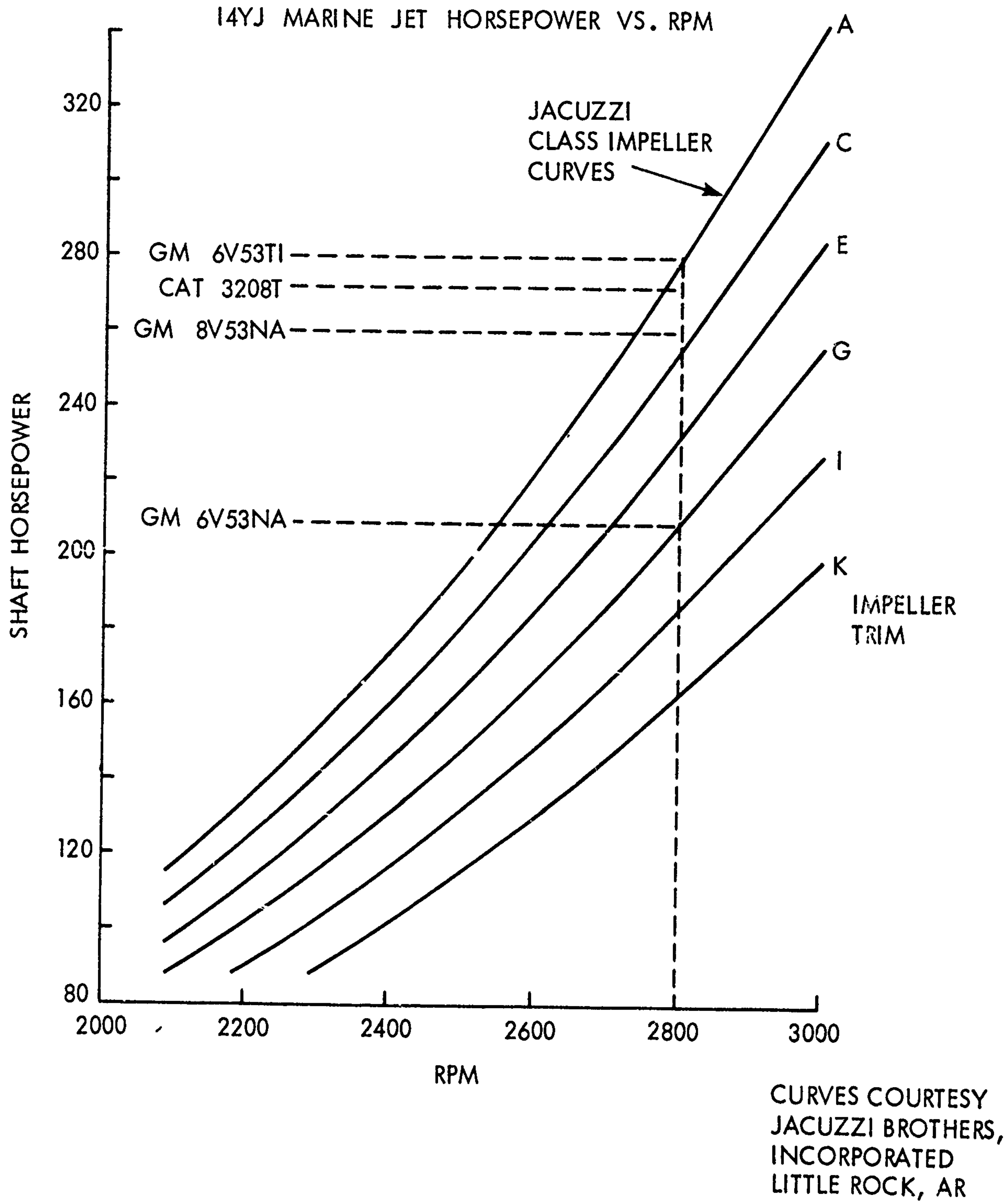

Figure 18. Impeller selection curves showing engines most suitable for MRBX

The MRBX hull design and pump jet propulsion system are two new concepts for the U. S. Coast Guard. Both were at first viewed with hesitancy and reservation by operating personnel. They are now accepted and are used to their maximum advantage.

The technical and operational evaluation of the prototype MRBX has provided a useful and effective means for establishing the worth of a new motor rescue boat concept to satisfy the needs of the U. S. Coast Guard for a fast, shallow draft, personnel rescue craft.

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